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ASSEMBLED BRIDGE CONSTRUCTION RISK ANALYSIS

ANALIZA RYZYKA BUDOWY MOSTU SKŁADANEGO

Abstract

Construction works need to be implemented in accordance with design documentation, technical and performance specifications as well as being carried out safely, on time and within budget. There are however various events, which can occur during the process of implementation, some as a consequence of the natural environment, others occupational, which can either disrupt the execution of and/or have a negative effect on the result of works. In such situations, the duration of works may be prolonged and thus the costs of a particular task may increase beyond the planned budget. A series of such events may lead to the final deadline and the total cost of works completion being greater than that which had been fixed in the contract. However, assuming the parameters of the PERT-beta probability distribution and three-point estimation method, it is possible to estimate and thus plan for two kinds of risks to works. The first is the risk to the deadline of works, and the second is the risk to the cost of works. Changes in risks are presented using charts of risks. These charts describe possible changes in the interval of risks [0, 1] depending on a series of increasing values of deadlines and costs affecting works completion.

Keywords: construction, risk, assembled bridge

Streszczenie

Roboty budowlane muszą być wykonane zgodnie z dokumentacją projektową oraz specyfikacją techniczną wykonania i odbioru robót, bezpiecznie, na czas i w ramach budżetu. Zdarzenia losowe, które mogą wystąpić w procesie realizacji, na placu budowy, w jego otoczeniu i w środowisku naturalnym mogą zakłócać wykonanie i pogarszać wyniki robót. W takiej sytuacji istnieje zagrożenie, że czas trwania i koszty poszczególnych robót mogą być większe niż planowano. Oznacza to także, że końcowy termin i całkowite koszty zakończenia robót mogą być większe niż ustalono w umowie. Zakładając rozkład prawdopodobieństwa PERT-beta i trzypunktową metodę aproksymacji parametrów rozkładu, można oszacować dwa rodzaje ryzyka realizacji robót. Pierwsze z nich to ryzyko terminu zakończenia prac, a drugie to ryzyko kosztów realizacji prac. Zmiany ryzyka są przedstawione za pomocą wykresów ryzyka. Wykresy opisują możliwe zmiany ryzyka w przedziale [0, 1] w zależności od ciągu rosnących wartości terminów i kosztów zakończenia robót.

Słowa kluczowe: budowa, ryzyko, most składany

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1. Introduction

Construction site works can be exposed to the impact of various events which can occur during the process of implementation, some environmental and others which may occur within the site itself. These events can, to varying degrees, disrupt the process of implementation and adversely affect its outcomes. These events can lead to an extension to the duration of works, an overdraft of the cost and a deterioration in the quality of the finished project. However, taking the requirements of construction law and the conditions of the contract implementation into account, work can only be implemented when the contractor can carry them out in accordance with the design documentation and technical specifications listed in the acceptance of works. This means that the random events may prolong the duration and increase the cost of works, but the qualitative and quantitative requirements of the contract must always be completely fulfilled.

2. Technical characteristics of the assembled bridge

The project used as an example in this paper is an assembled bridge, which will be used as a temporary bypass [1]. The overall length of the bridge is 78 m. It is a continuous three-span beam: 24 m + 30 m + 24 m (Fig. 1). The spans were founded on the two indirect assembled supports and two bank supports. The superstructures SPS-69 of the both indirect supports were founded on 24 timber piles, each with a diameter 329 mm (Fig. 3, 4). Bank supports were designed as spot footings with road reinforced concrete slabs. The bridge was connected to the existing road system through access dirt roads which were improved with gravel. Total length of the access roads is 328 m.

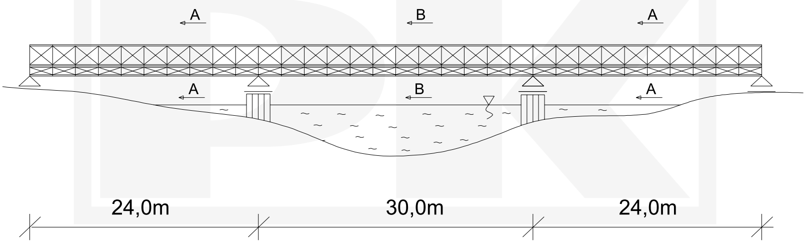

Fig. 1. Longitudinal section of the bridge span structure

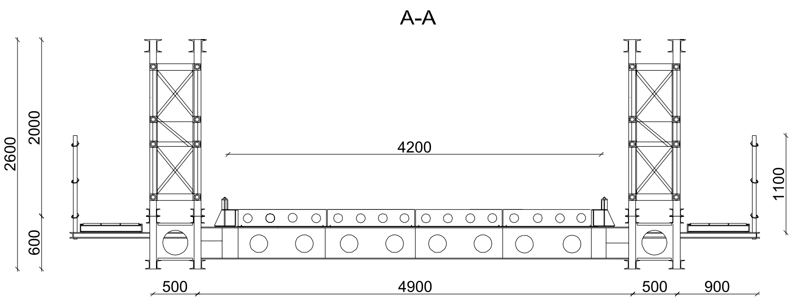

Fig. 2. Cross section of the bridge span structure: A-A, B-B

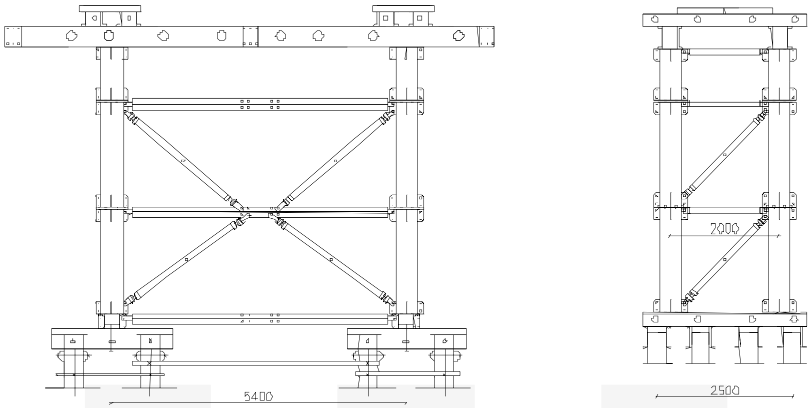

Fig. 3. Superstructure SPS-69 of the bridge indirect supports: a) front view, b) side view

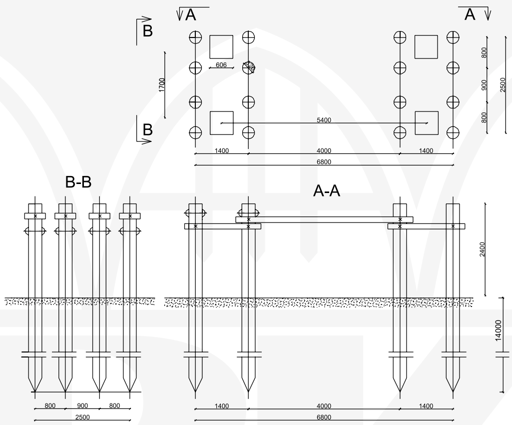

Fig. 4. Configuration of the pile foundation of the bridge indirect supports

3. Organization of the works implementation on the construction site

The erection of the assembled bridge involves two basic groups of works. The first is an erection of indirect bank supports. The second is an assembling works on the mounting site pushing the assembled parts of the span structure on the supports.

According to the plan, indirect supports will be set using an assembling ferry with the pile-driver. Bank supports will be set using a crane truck. The span structure will be constructed from a two part element at the mounting site. After assembly, each completed element will then be pushed onto the supports. Works will be executed on separate fronts of works by specialized working brigades. The cost of each particular work task, as well as the total cost of works have been specified in the estimate. Technology and organization of works have been described using a technological bridge structure model and a construction works technology model $\mathscr{L} = \{ \langle \mathbf{H}, \mathbf{K}, \mathbf{T} \rangle, \mathbf{S} \}$ [2, 3]. Graph $\boldsymbol{G}$ is presented on Fig. 1, as well as data prepared for the calculation in table 1. describ the interdependence and sequential relationships of all construction works.

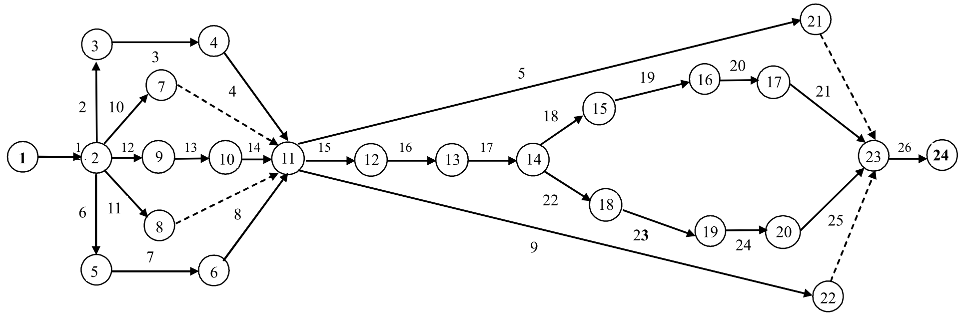

Fig. 5. Graph ***G*** that describes interdependences and sequential relationships of all construction works

The next step is connected with the assessment of risks whereby foreseeable conditions of works to be implementation have been analyzed. Likely random events, their impact on the process and results of work, as well as their execution have been considered. Coefficients of optimism and pessimism with regard to duration and cost have been estimated. Using the coefficient of optimism p_o the probable maximal reduction is given, while using the coefficient of pessimism p_p the probable maximal increase of most probable durations and costs have been calculated. Moreover, the PERT-beta probability distribution and the three-point estimation method of the stochastic parameters of this distribution have been applied [4, 5]. Then, using the optimistic and pessimistic values of durations and costs, the expected durations and expected costs of particular works have been calculated. Finally, the expected total cost of works execution is the sum of the expected costs of all executed works. The earliest final deadline of the works completion can be calculated as a solution of the following scheduling problems [2, 3]:

– the earliest final deadline and the earliest start time of the works:

$$E[T] = \min \sum_{i=1}^{i=m} E[V_i],$$

$$E[V_k] - E[V_i] \geq E[T_j] \quad \text{for} \quad u_j \in \mathbf{U}, j = 1, 2, ..., n, \langle y_i, u_j, y_k \rangle \in \mathbf{P} \tag{1}$$

$$E[V_i],\ E[V_k] \geq 0 \quad \text{for} \quad i = 1, 2, \ldots, m\,.$$

– the earliest final deadline and the latest finish time of the works:

$$E[T] = \max \sum_{i=1}^{i=m} E[V_i],$$

$$E[V_k] - E[V_i] \geq E[T_j] \quad \text{for} \quad u_j \in \mathbf{U}, j = 1, 2, ..., n, \langle y_i, u_j, y_k \rangle \in \mathbf{P} \tag{2}$$

$$E[V_m] \leq \min E[V_m]$$

$$E[V_i],\ E[V_k] \geq 0 \quad \text{for} \quad i, k = 1, 2, \ldots, m\,.$$

A schedule of the works may also be developed using any computer-based scheduling system.

Table 1

The cost estimate of works: $p_o = 0{,}15$ – coefficient of optimism, $p_p = 0{,}2$ – coefficient of pessimism

No of work	Number of event		Name of work	Duration [*hours*]						Direct costs [PLN L18]					
				Moderate conditions				Favorable conditions	Hard conditions	Moderate conditions				Favorable conditions	Hard conditions
	y_i	y_k		$E[T_j]$	$\underline{T}_j$	T_j	$\overline{T}_j$	$E^p[T_j]$	$E^n[T_j]$	$E[\underline{K}_j]$	$\underline{K}_j$	K_j	$\overline{K}_j$	$E^p[K_j]$	$E^n[K_j]$
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1	1	2	Development works	10	8	10	13	10	10	1 393	1 096	1 370	1 781	1 375	1 437
2	2	5	Construction of the ferry for the pile-driver and mounting of the support No. 1	4	3	4	5	4	4	1 925	1 515	1 894	2 462	1 900	1 987
3	5	6	Construction of the pile foundation of the intermediate support No 1	49	38	48	62	48	50	24 819	19 530	24 412	31 736	24 494	25 613
4	6	11	Assembly of the superstructure of the intermediate support No 1	21	16	20	26	20	21	6 178	4 861	6 077	7 900	6 097	6 375
5	11	12	Dismantling of the ferry for pile-driver and mounting of the support No 1	5	4	5	6	5	5	2 531	1 992	2 489	3 236	2 498	2 612
6	2	7	Construction of the ferry for the pile-driver and mounting of the support No 2	4	3	4	5	4	4	1 925	1 515	1 894	2 462	1 900	1 987
7	7	8	Construction of the pile foundation of the intermediate support No 2	49	38	48	62	48	50	24 819	19 530	24 412	31 736	24 494	25 613
8	8	11	Assembly of the superstructure of the intermediate support No 2	27	22	27	35	27	28	6 178	4 861	6 077	7 900	6 097	6 375
9	11	13	Dismantling of the ferry for pile-driver and mounting of the support No 2	5	4	5	6	5	5	2 531	1 992	2 489	3 236	2 498	2 612
10	2	9	Construction of the bank support of the left abutment	14	11	14	18	14	15	5 272	4 149	5 186	6 742	5 203	5 441
11	2	10	Construction of the bank support of the right abutment	14	11	14	18	14	15	5 272	4 149	5 186	6 742	5 203	5 441
12	2	3	Preparation of the mounting site at the left bank	2	2	2	3	2	2	4 351	3 424	4 280	5 564	4 294	4 490
13	3	4	Execution of the mounting beak	2	1	2	2	2	2	237	187	233	303	234	245
14	4	11	Assembly of the first part of the span structure with single elements	18	14	18	23	18	19	5 626	4 427	5 534	7 194	5 552	5 806
15	11	14	Sliding of the assembled part of the span structure at the left bank support and the intermediate support No 1	4	3	4	5	4	4	496	391	488	635	490	512
16	14	15	Assembly of the second part of the span structure with single elements	12	10	12	16	12	13	4 689	3 689	4 612	5 995	4 627	4 838
17	15	16	Sliding of the assembled part of the span structure at the intermediate support No 2 and right bank support	9	7	9	11	9	9	804	633	791	1 029	794	830
18	19	20	Liquidation of mounting site at the left bank	2	1	2	2	2	2	4 663	3 669	4 587	5 963	4 602	4 812
19	20	21	Assembly of the entrance span at the left bank	2	2	2	3	2	2	183	144	180	234	180	189
20	21	22	Shaping the embankment at the left abutment	12	9	12	15	12	12	1 876	1 476	1 845	2 399	1 851	1 936
21	22	25	Construction of the gravel route at the left abutment	16	13	16	20	16	16	25 834	20 328	25 410	33 033	25 495	26 659
22	18	19	Dismantling of the mounting beak	1	1	1	2	1	1	198	156	195	254	196	205
23	20	23	Assembly of the entrance span at the right bank	2	2	2	3	2	2	183	144	180	234	180	189
24	23	24	Shaping the embankment at the right abutment	9	7	9	12	9	9	1 413	1 112	1 389	1 806	1 394	1 458
25	24	25	Construction of the gravel route on the right abutment	14	11	14	18	14	14	19 479	15 328	19 159	24 907	19 223	20 101
26	25	26	Finishing works	2	1	2	2	2	2	875	688	860	1 119	863	903
									Total	153 751		151 230		151 734	158 666

4. Risk assessment of the assembled bridge erection

The risk to works describes the scope of the threat which may lead to the project taking longer and being more expensive than planned. From this point of view a risk to the final deadline and a risk of the total cost of works should be estimated. The risk to the final deadline indicates how great the threat is to the final term of works completion which may thus be exceeded. The risk of total cost indicates how great the threat is to the final cost of works completion, which may be greater than that fixed in the cost estimate. Measure of risk is the probability of exceeding the specified values of the final deadline and the total cost of works completion. The risk to the final deadline and total cost are calculated for the sequence of rising values of the final deadline and the total cost of the works according to the following formulas [2, 3]:

1) the risk of the final deadline:

$$P\left[E[T]\geq t\right]=1-P\left[E[T]\leq t\right]\approx\ 1-Z\left[\frac{t-E[T]}{\sqrt{D^2[T]}}\right] \tag{3}$$

2) the risk of total cost:

$$P\left[E[K]\geq k\right]=1-P\left[E[K]\leq k\right]\approx\ 1-Z\left[\frac{k-E[K]}{\sqrt{D^2[K]}}\right] \tag{4}$$

The results of risk analysis are presented in the charts of risk (Fig. 6, 7) also called charts of contingency. These charts show the changes of probability in the range [0, 1] for different values of final deadline and different values of the total cost of works completion.

5. Conclusions

The proposed rules of risk assessment of the assembled bridge construction provide the possibility of making a quantitative risk evaluation that is, the estimation of a threat which could jeopardize the contractual final deadline and where the total cost of works completion may be exceeded. Looking at the risk to the final works on the bridge, the probability of exceeding the time limit seems likely, while the cost of works completion may lead to an overdraft. For these quantities the lowest values of the final deadline (t_{min}) and the total cost (k_{min}) of works completion are estimated. The probability of exceeding these values amount to $p(t_{min})$ = 1,0 and $p(k_{min})$ = 1,0. Moreover, the largest values of the final deadline (t^{max}) and the total cost of works completion (k^{max}) are estimated. The probability of exceeding these values amount to $p(t^{max})$ = 0,0, $p(k^{max})$ = 0,0. Such analysis, simplify decision making during the negotiation process and the determination of competitive final deadline and total cost of the works completion. Simultaneously it allows making the decisions which do not expose the contractor to excessive risk for not meeting the conditions of the agreement.

In the considered case, the normative total cost k^n = 151 230 PLN of the works is close to the expected total cost $E[K^p]$ = 151 734 PLN in favorable conditions of works implementation. But, the expected total cost $E^m[K]$ = 153 751 PLN in moderate conditions and the expected

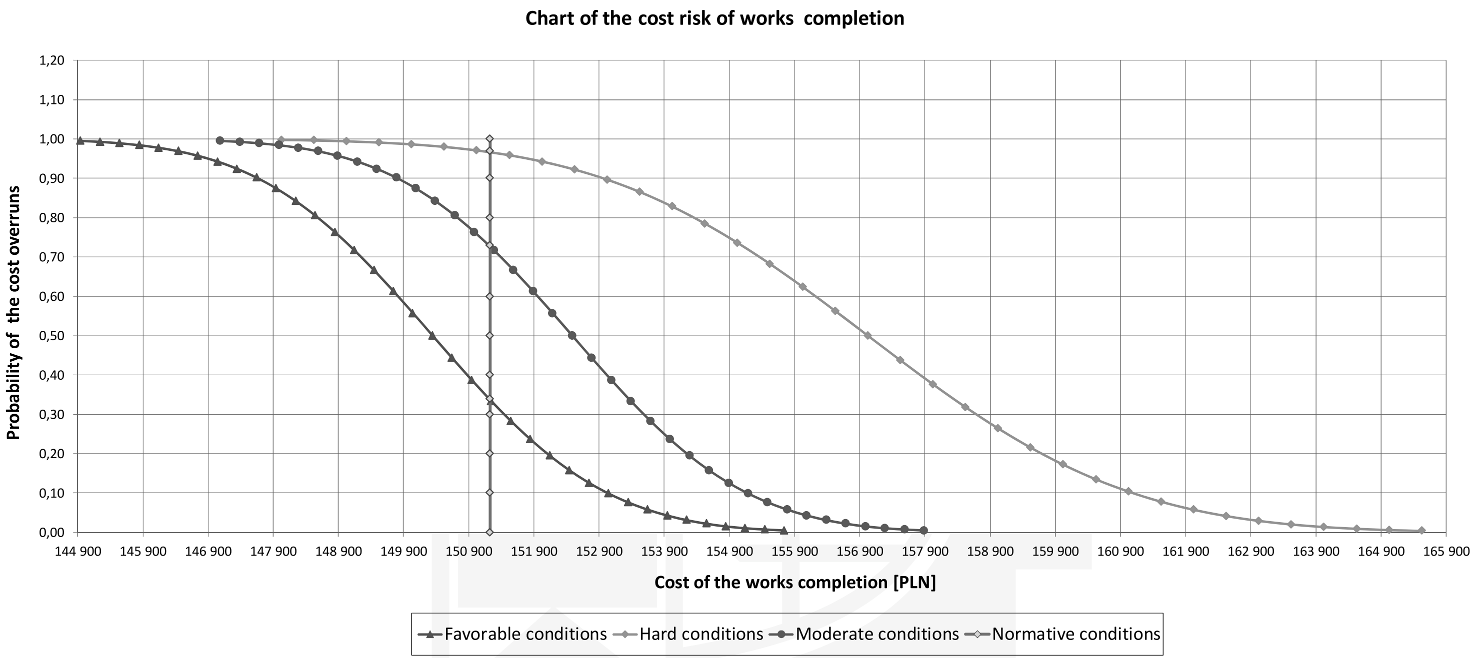

Fig. 6. Charts of the cost risk of works completion

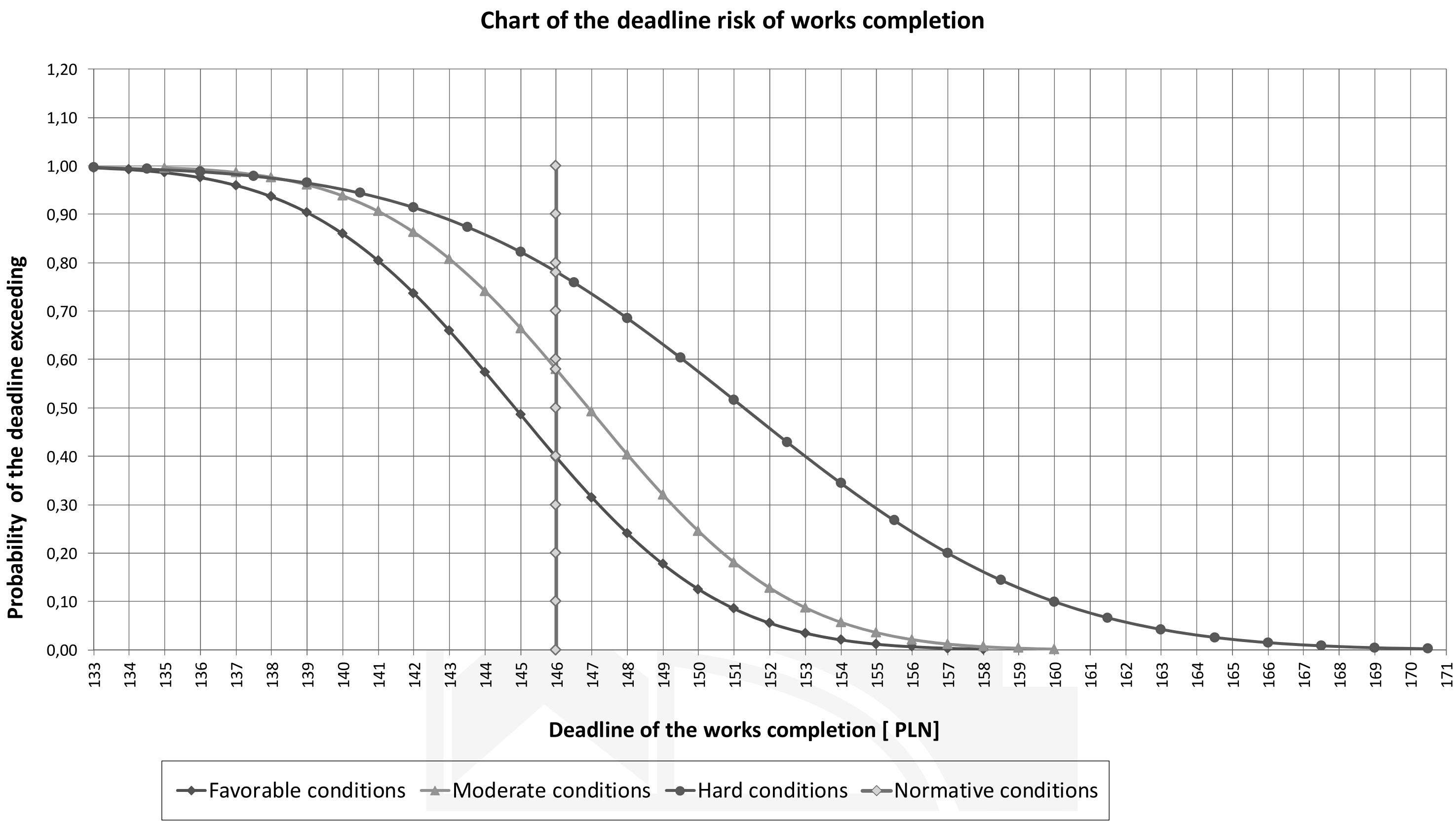

Fig. 7. Charts of the deadline risk of works completion

total cost $E^t[K^t]$ = 158 666 PLN in difficult conditions of works, implementation is greater than normative total cost. When it comes to the normative final deadline t^n = 146 hours corresponds to the expected final deadline $E[T^p]$ = 146 hours of works completion in the favorable conditions. However, the expected final deadline $E[T^m]$ = 148 hours in moderate conditions may occur later than in the normative conditions. Similarly, the expected final deadline $E[T^t]$ = 153 hours in the hard conditions of works completion may occur even later.

Furthermore, taking the shape of the risk curves into consideration, one can explore how the risk to the final deadline and risk of total cost of the works completion may fluctuate along with the changes of contractual values of these quantities. One can also confirm that estimating the final deadline and total cost of the works based only on the normative data may be the cause of incorrect determination of the contractual values. It should also be noted that the described differences in the comparison between normative conditions are the greater the more turbulent the actual conditions of work implementation. Of course, the proposed approach to risk analysis allows the planner to specify these differences and estimate how great they are.

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